GROWTH OF RICE PLANTS TO MATURITY IN NUTRIENT CULTURE

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GROWTH OF RICE PLANTS TO MATURITY IN NUTRIENT CULTURE [1]

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WITH TEN TEXT FIGURES

For growing rice plants in artificial medium, RS-17 may be used during the first 45 days. During the succeeding period, a solution containing about one-third as much nitrogen as RS-17, three times as much phosphate and from two to five times as much potassium is preferable. In this study, cultures VIII and XIII were found best.

In most of the local studies on the nutritional requirements of rice plants (cf. Espino, 1920, 1922; Espino and Estioko, 1931; Palisoc, 1928; Gines, 1930; Macasaet, 1932; Velasco *et al.*, 1955; and Velasco and Fertig, 1956), the cultures were terminated not long after the seedling stage, i.e., 30 to 45 days of age. Only one attempt was made to study the nutrition of rice during the vegetative stage (Hsieh, 1941). The apparent paucity of interest in studies dealing with rice in its later stages of development is traceable to the longer duration of the experiments, hence, the slower turnover of culture facilities and greenhouse space. The impatience of workers arising from the fact that they have to wait about 150 days for results bearing on their hypotheses may also be one reason for the lack of interest.

The writers are, however, aware that in order that knowledge on plant nutrition may be more useful in interpreting the observations on fertilizer and cultural experiments in the field, it should include information on the various needs and responses of the plants during the different stages of their development. These experiments were started to find a good culture solution for the later stages of the development of rice. With a culture solution which allows growth comparable with that obtaining under field conditions, the studies on the responses of rice to the various factors of the environment will have a sounder basis and will assume more meaning.

The experiments were performed in the Department of Agricultural Botany, College of Agriculture, U.P., from March, 1956, to

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June, 1958. Because the first three experiments were preliminary in nature and were essentially repeated in experiments 4 and 5, they will not be reported here, except as they bear on the results of the latter two experiments.

MATERIALS AND METHODS

Peta, a promising lowland variety which matures in about 150 days and which is relatively less sensitive to varying lengths of day, was used in the experiments. The latter quality makes it possible to run cultures throughout the year without too much apprehension that the changing seasons might markedly affect the results.

The seeds were laid out on cheese cloth suspended over a beaker filled with water. When the seedlings were about 12 days old, they were transferred to RS-17 (Velasco and Fertig, 1956). The standard micro-nutrients of Arnon (1938) were added, and iron, as ferric chloride solution, was added at intervals and was calculated to amount to a total concentration of 5 ppm of the element. Because distilled water could not be had in the right quantity, rain water was used in these cultures. And in one or two instances, tap water had to be used. To obviate the precipitation of iron because of the fairly high pH of the solution with tap water, dilute sulphuric acid was added to adjust the pH to 4.8.

At the start of the cultures, two seedlings were allowed to each liter of solution. Depending on the size of the plant, solutions were changed at 4- to 14-day intervals. The volume of solution allowed each pair of plants was increased to 3.5 liters when the plants were 45 days of age and to 15 liters when they were 60 days of age. Treatment with the various modifications of RS-17 started when the plants were 50 to 60 days of age. Cultures were run in four or more replications.

The amount of solution lost during any growth interval was arbitrarily considered as amount absorbed. This, however, includes evaporation from the free water surface, and whatever little amount spilled during changing. The height of tops, length of roots, and visual changes were recorded at the time the solutions were changed. At harvest, the weights of grains and straw were taken.

EXPERIMENTS AND RESULTS

Experiment 4

This experiment was conducted from July 10 to December 9, 1957, to determine the effects of various levels of nitrogen, phospho-

rus, potassium, and calcium on the growth and yield of rice. In previous experiments, there were indications that a higher phosphate level than that found in RS-17 could be beneficial to rice in the later stages. For instance, in Experiment 3, the plants given 2.1 milliequivalents per liter (meq/l) of phosphate maintained very healthy roots and dark green broad leaves up to the time of harvest. In contrast, the roots of plants in RS-17 with 0.6 meq/l of phosphate started to disintegrate at about boot stage and this culminated in the total destruction of the root system at the stage of flower emergence. It would therefore seem that for maintenance of a healthy root system, the plants should receive more phosphate than that provided by RS-17.

The rice plants which had been grown in RS-17 were transplanted to different culture solutions at 50 days of age (table 1).

TABLE 1.—*Composition of solutions in experiment 4*

	CULTURE NUMBER			
	RS-17	VI	VII	VIII
	Concentration, 10^{-4} M			
Salts				
$Ca(NO_3)_2$	7	5	3	3
KNO_3	3	–	–	–
$(NH_4)_2SO_4$	5	–	5	2
$MgSO_4$	3	5	5	5
KH_2PO_4	2	7	7	5
KCl	–	3	–	5
	Milli-equivalents per liter			
Element				
Nitrogen	2.7	1.0	1.6	1.0
Phosphorus	0.6	2.1	2.1	1.5
Potassium	0.5	1.0	0.7	1.0
Calcium	0.4	1.0	0.6	0.6
Magnesium	0.6	1.0	1.0	1.0

At 47 days of treatment, culture VIII appeared to be the best in growth, followed by culture VI. They had healthy root system, upright leaves and good sized tillers. However, their leaves were light green to yellowish green in color. In contrast, RS-17 and culture VII had dark-green leaves. They were, however, not desirable because they were weak, their leaves arching and breaking crosswise near the middle. In addition, they formed tillers continuously up to maturity.

This crop was attacked by stem borers and culture VII suffered greatly from it. Its extreme susceptibility may be a reflection of

the wide nitrogen-to-calcium ratio (2.7:1), the plants being very succulent and their mechanical tissues poorly developed. Another consequence of the wide nitrogen-to-calcium ratio was the stubby root system in this culture.

In all cultures, black spots, suspected to be a symptom of insufficient manganese, were noticed on tips of leaves and on the grains. In the subsequent experiment, manganese was raised to twice the level recommended by Arnon (1938).

Figure 1 shows the amount of solution absorbed by plants during their life cycle. RS-17 absorbed the highest, followed by culture VI and culture VIII. The computed daily absorption in RS-17 gradually increased with age, reaching a maximum at 104 to 131 days old; then it tapered off towards maturity of the grains. The period of maximum absorption corresponded to the unfolding of the flag leaf to about the dough stage of the grains. Culture VI and VIII had a

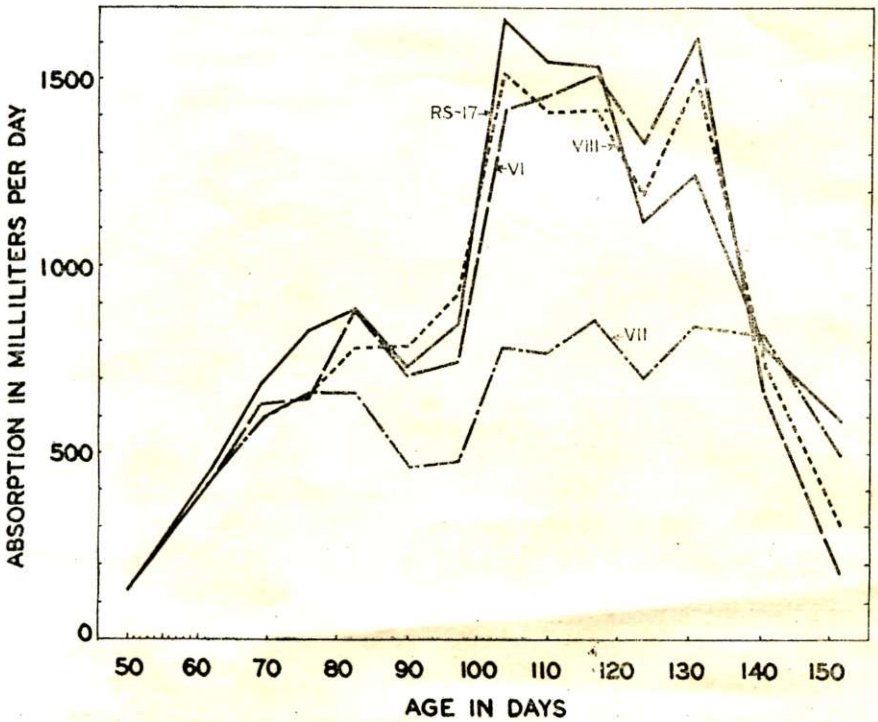

Fig. 1.—Amount of solution absorbed in milliliters per day.

similar pattern of absorption as RS-17. Culture VII, however, showed no distinct peak of daily absorption which may have been due in part to its poorly developed root system.

The trends of growth as gauged by the height of tops, length of roots and number of tillers are shown in figures 2, 3, and 4. RS-17 served as control and cultures VI and VIII were the two high-yielding cultures. There was rapid growth in height of tops up to about 90 days of age; then a slack up to 110 days. The slight resurgence in growth noticeable at 120 days might have been due to the lengthening of the internodes following the emergence of the panicles. Culture VI, which did not receive ammonium nitrogen, was the tallest. It was also very light green, suggesting a condition of partial etiolation. Espino (1920) reported that rice seedlings without ammonium nitrogen were extremely chlorotic and did not live long. Apparently in this late vegetative stage rice plants did not suffer as drastically as the seedlings from lack of ammonium nitrogen.

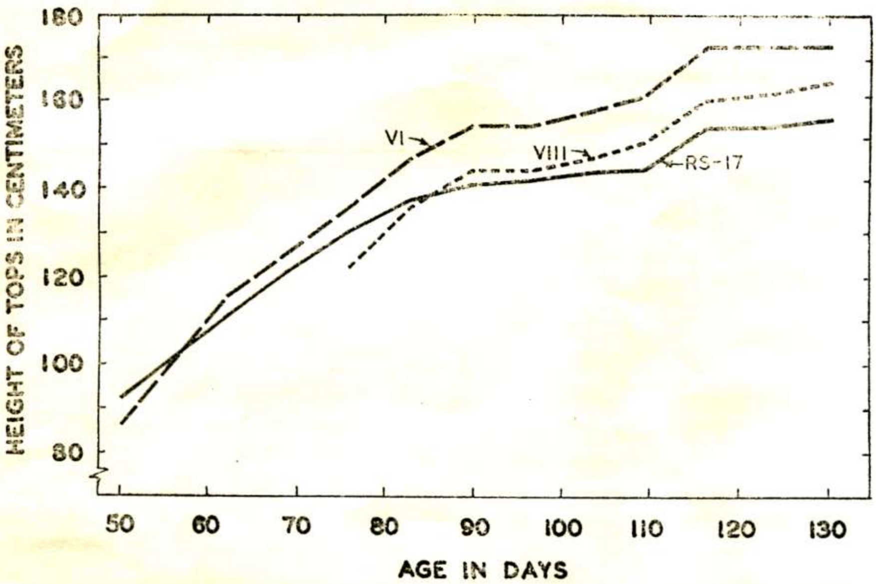

Fig. 2.—Height of tops in centimeters.

Again, culture VI had very long roots, a characteristic of plants not receiving sufficient nitrogen. When one considers that culture VIII received the same amount of nitrogen as culture VI (except

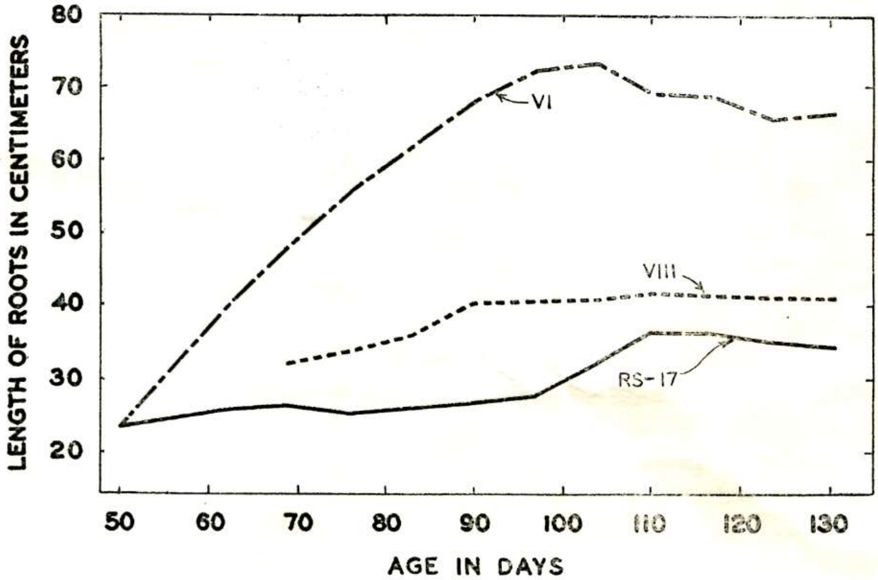

Fig. 3.—Length of roots in centimeters.

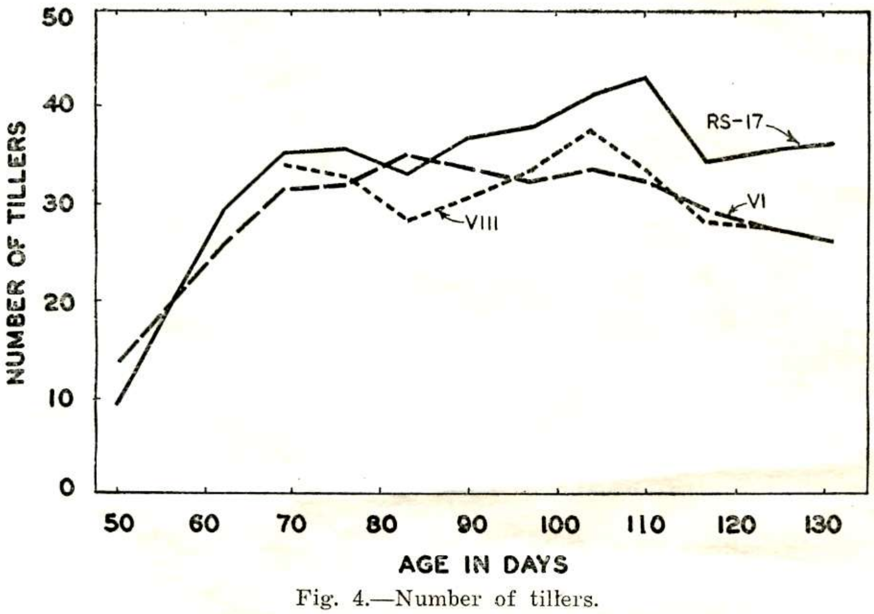

Fig. 4.—Number of tillers.

that two-fifths of it was in the form of ammonium) and yet did not show the same mild symptoms of nitrogen deficiency, one is apt to discount the effectiveness of nitrate nitrogen in rice nutrition. RS-17 had the shortest root system because it underwent a continuous process whereby old roots decayed and got replaced by newly formed, short, stubby ones. Apparently RS-17 had more nitrogen than what was good for the plants.

The tillers were at maximum from 70 to 110 days of age. Thereafter, the tillers diminished and at the final counting came down to about 70 per cent of the maximum. RS-17 was conspicuous in that it continued producing new tillers even after panicles had emerged from the older ones. At 152 days old when the panicles were finally harvested, RS-17 had, on the average, 20.3 ripe panicles and 12.2 immature ones; culture VI, 23.0 ripe panicles and no immature ones; culture VII, 11.2 ripe and 6 immature panicles; and culture VIII, 23.0 ripe and no immature panicles. Or, of the 36 tillers of RS-17 at 131 days old, only 56 per cent produced harvestable panicles; of the 26 in culture VI, 88 per cent; of the 21 in culture VII, 53 per cent; and of the 26.33 in culture VIII, 88 per cent produced harvestable panicles. RS-17 and culture VII wasted themselves away by producing tillers which either did not head or headed too late to be of any value at all.

The average dry weight of grains produced by RS-17 was 39.8 grams; culture VI, 68.1 grams; culture VII, 23.9 grams; and culture VIII, 60.7 grams. On the basis of 160,000 hills to a hectare, culture VI gave a computed yield of 10.88 tons or 247 cavans. The significance of differences in yield among cultures was not determined because of the unaccountable disturbance from stem borers. Culture VI, although the highest yielder, will not be used in further trials because of the very abnormal behaviour of the plants. In addition to yield, the closeness in characteristics of solution-grown plants to field-grown plants is a criterion used in the choice of a culture solution.

The two high yielding cultures (VI and VIII) contain about one-third as much nitrogen as RS-17. This seems to suggest that the need of the rice plants for nitrogen in the later stages of development is not very great. In contrast, its rate of ammonium and nitrate absorption from RS-17 was relatively high (fig. 5). Apparently, rice plants lack the capacity to determine for themselves the quantity and proportion of nutrients for best yield. The phosphate

contents of the high yielding cultures are about 3 times as much; their potassium, twice as much; and calcium, about one-half to two-thirds as much.

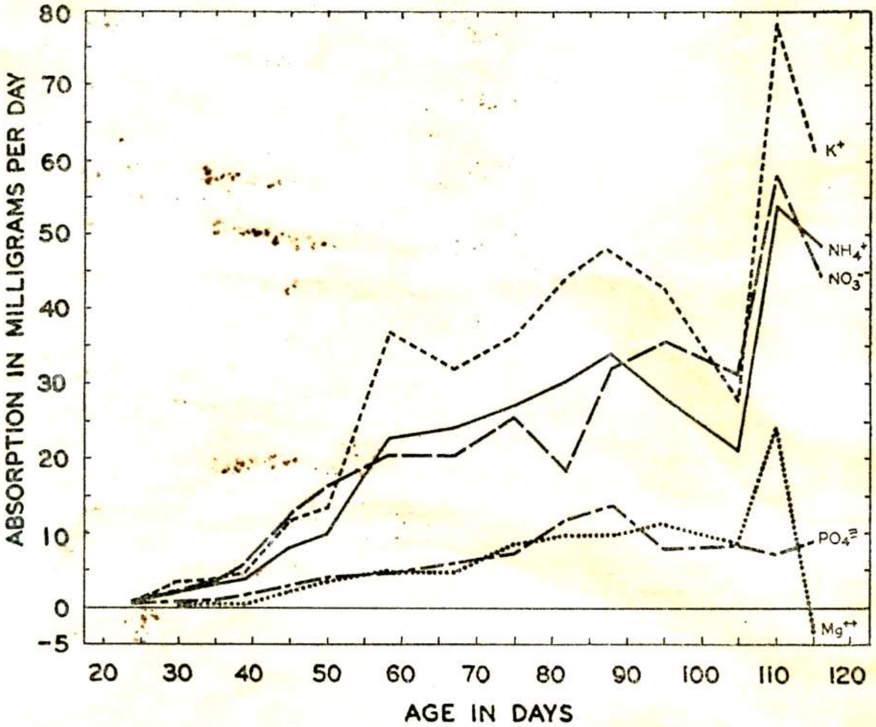

Fig. 5.—Absorption from RS-17 in milligrams of the nutrient element per day.

Experiment 5

Although it seemed certain that for best grain formation a fairly low level of nitrogen was necessary, there were not enough indications as to the optimum level and proportions of phosphate and potassium. The present experiment conducted from February 12 to June 18, 1958, was intended to explore the latter aspect more thoroughly.

After a preliminary growth period in RS-17, the plants were transferred to the different solutions at the age of 61 days as shown in table 2.

In cultures VIII, IX and X, phosphate was increased while potassium remained the same; in cultures XI, XII and XIII, potassium

was increased while phosphate was held constant; and in cultures XIV and XV, both phosphate and potassium increased at the same rate.

TABLE 2.—*Composition of solutions in experiment 5*

	CULTURE NUMBER							
	VIII	IX	X	XI	XII	XIII	XIV	XV
	Concentration in 10^{-4} M							
Salts								
$Ca(NO_3)_2$	3	3	3	3	3	3	3	3
$(NH_4)_2SO_4$	2	2	2	2	2	2	2	2
$MgSO_4$	3	3	3	3	3	3	3	3
KH_2PO_4	5	5	5	3	3	3	5	7
KCl	5	5	5	12	17	22	10	13
NaH_2PO_4	–	2	3	–	–	–	–	–
	Milli-equivalents per liter							
Element								
Phosphorus	1.5	2.1	2.4	0.9	0.9	0.9	1.5	2.0
Potassium	1.0	1.0	1.0	1.5	2 0	2.5	1.5	2.0

Because it was anticipated that the fairly long days in May and June would delay the onset of flowering, the plants were given 10-hour days at 63 days of age. This was done by putting over the plants a cage lined with black satin cloth at 4:00 p.m. and removing it at 6:00 a.m.

Although luxuriant in the early stages of the preliminary growth period, the plants in RS-17 showed signs of unhealthiness at 45 to 60 days. The leaves were dark-green but flabby (fig. 6). After about a week in the test solutions which were low in nitrogen, the plants produced erect and rigid young leaves.

Figure 7 is a plot of the fresh weight of plants in four of the cultures. Culture VIII served as the control, culture X had the highest phosphate concentration, culture XIII had the highest potassium, and culture XV had the highest combination of phosphate and potassium. There was a sustained increase in fresh weight up to 110 days. Cultures VIII, X and XIII suffered a slight loss in weight at 117 days, the last weighing. This terminal loss in weight was probably due to drying of the straw, concomitant with the ripening of the grains. Culture XV was different in that its increase in weight was sustained even up to the last weighing. This was another sign of the continued tillering and vegetative growth in this culture.

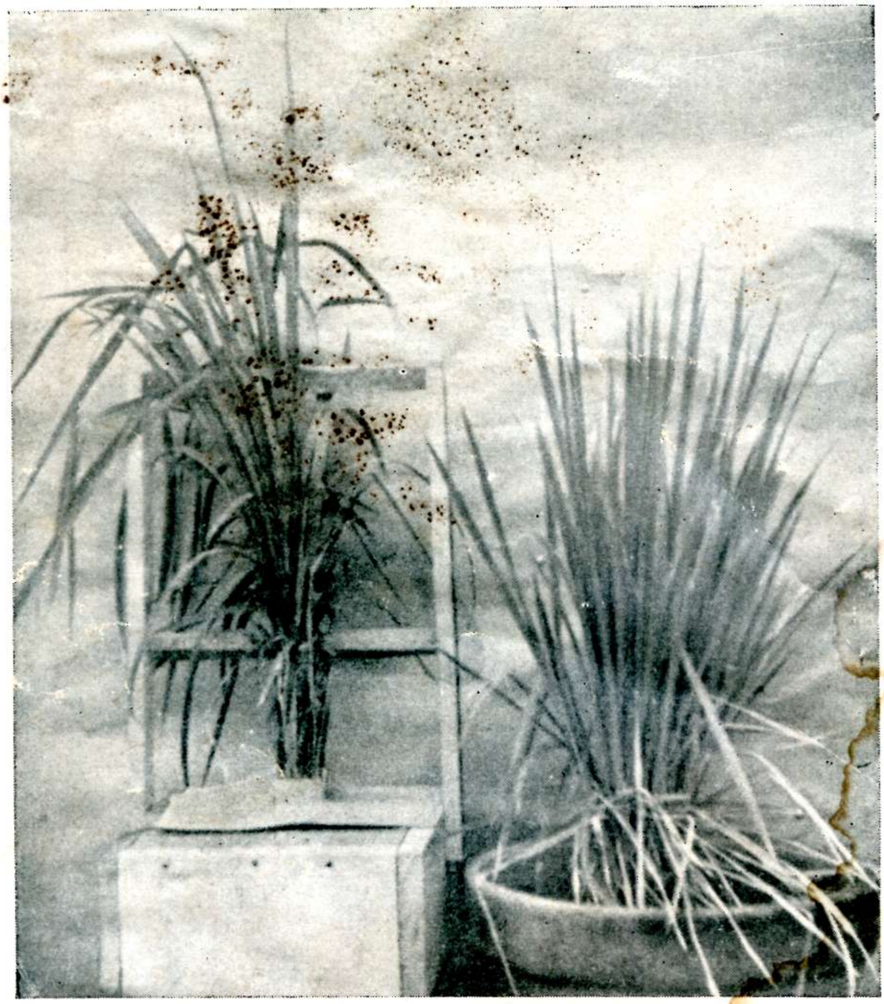

Fig. 6.—Comparison of rice plants grown in RS-17 and soil-grown plants at 64 days of age. Note the flabby leaves in the solution-grown plants.

Height of tops, length of roots and number of tillers are presented in figures 8, 9 and 10.

Culture X was consistently the tallest of the cultures. Cultures VIII, XIII and XV were about equal in height; their differences were probably just random fluctuations. The terminal resurgence in growth noted in Experiment 4 was not apparent in these cultures.

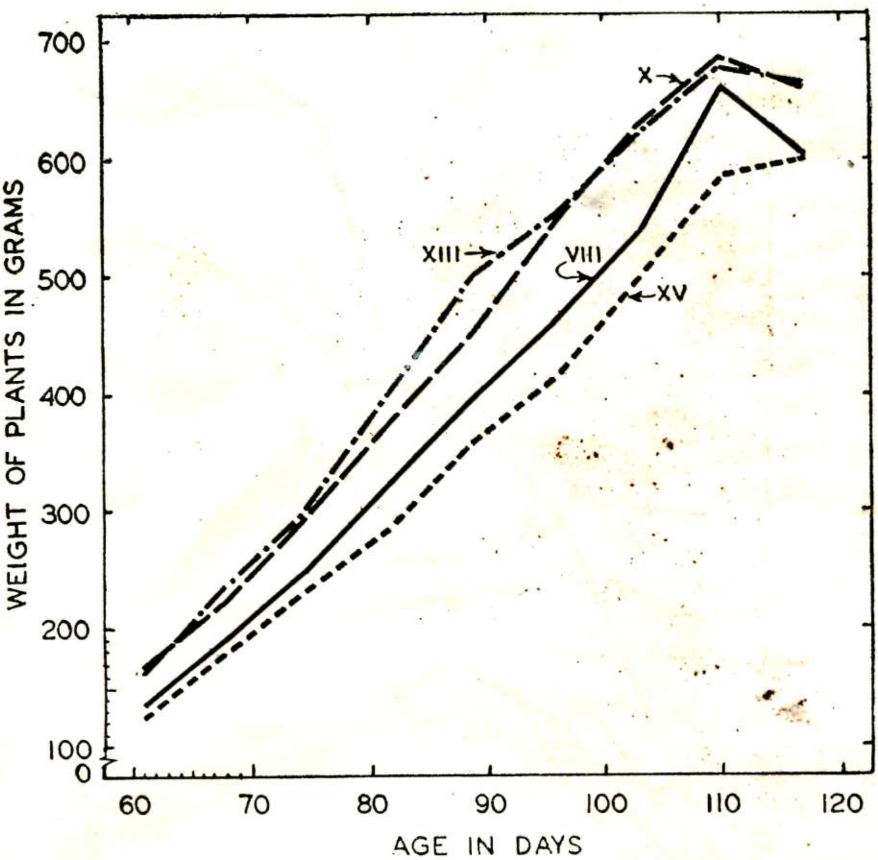

Fig. 7.—Fresh weight of plants in grams.

The length of roots as plotted tended to trace a parabolic curve attaining a near-maximum value at 89 days of age and then little or no growth was made thereafter. The roots of culture XIII were longer than those of cultures VIII and X. Observations on culture XV fluctuated very greatly. The sudden drop at 110 to 117 days of age is a reflection of the general foul-rotting which set in. Its cause has not yet been ascertained.

In cultures VIII, X, and XIII, the tiller counts attained their maxima at 75 to 82 days. These were sustained up to the last counting. In contrast, culture XV continued producing tillers up to the end of the experiment. The late-formed tillers did not head.

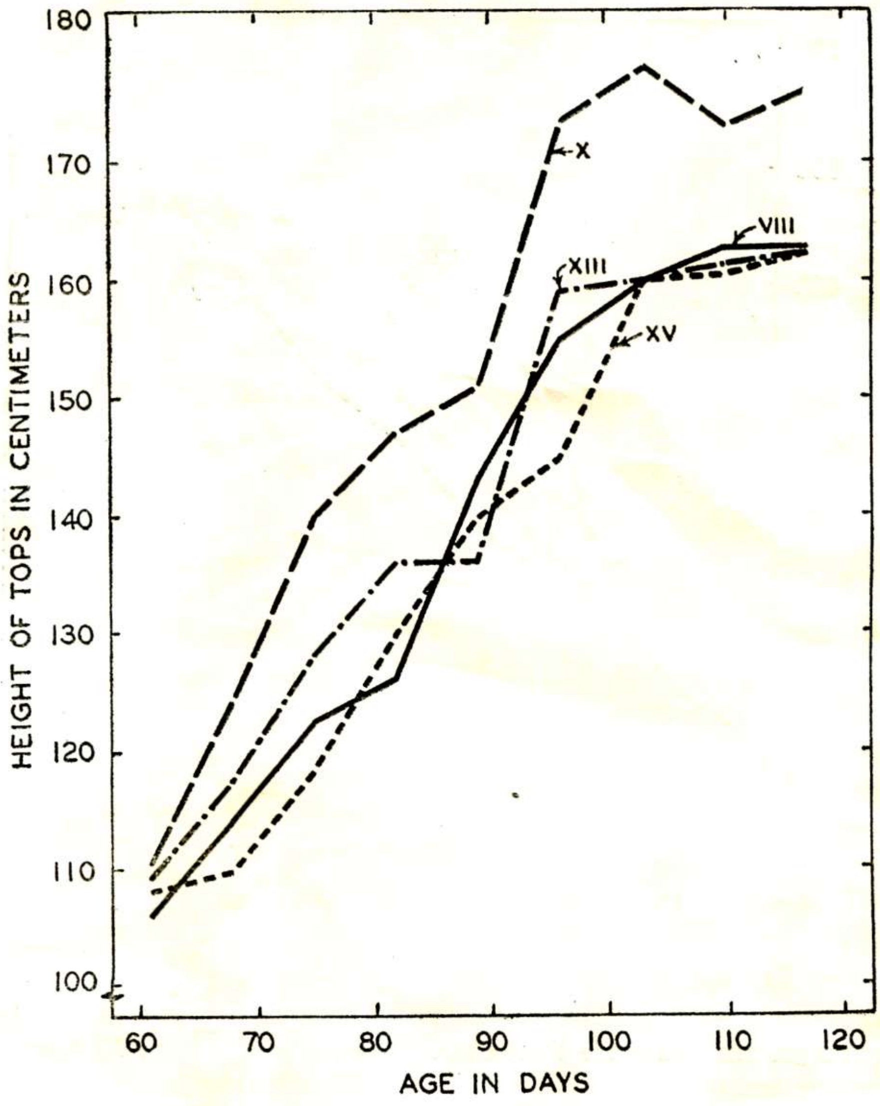

Fig. 8.—Height of tops in centimeters.

The amount of solution absorbed are presented in table 3. The totals of these cultures were much lower than those in Experiment 4, partly because of the shorter growing period. If each hill is allotted 625 square centimeters, then a crop of rice under the conditions of

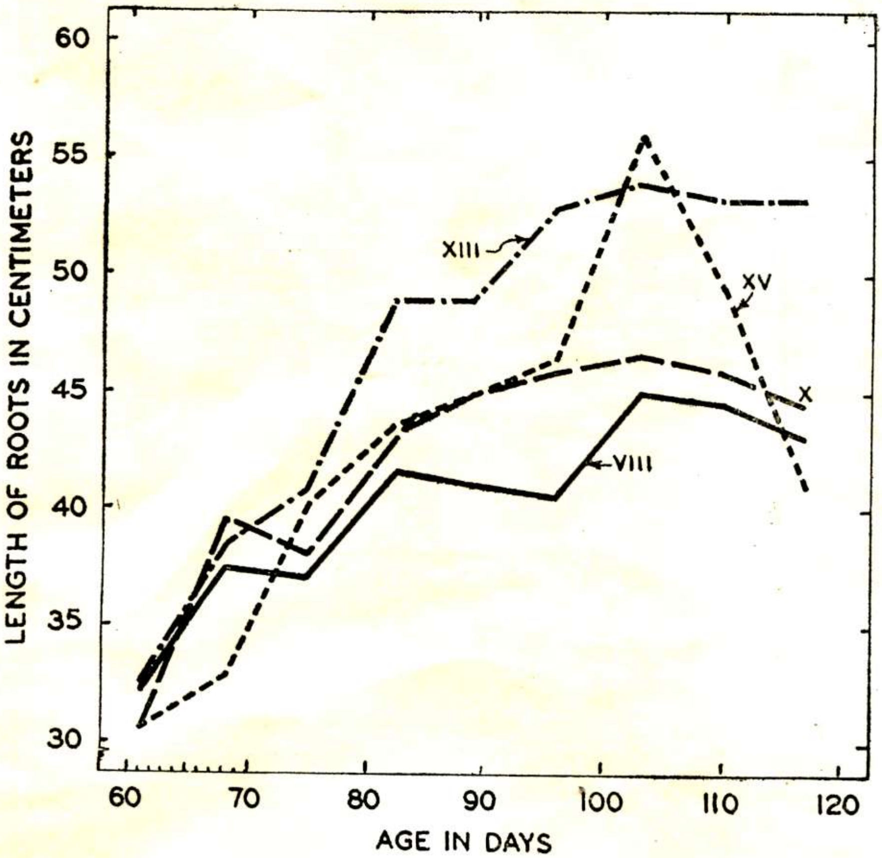

Fig. 9.—Length of roots in centimeters.

culture XII will require 107.9 hectare-centimeters of water. This is the same order of magnitude which Abarra (1952) found for a crop of Elon-elon grown in pots.

The amount of solution needed to produce a gram of dry matter ranged from 452.06 ml. in culture XV to 492.30 ml. in culture XI. A crop of Elon-elon grown in pot culture may need 559 milliliters of water to produce one gram of dry matter. The difference may be accounted for by the longer growing period of Elon-elon.

On the average, culture XI flowered in 99 days; cultures VIII, X, and XIV, in 100 days; and cultures IX, XII, XIII, and XV, in 101 days. Ranges of flowering in most cultures were within 10 days.

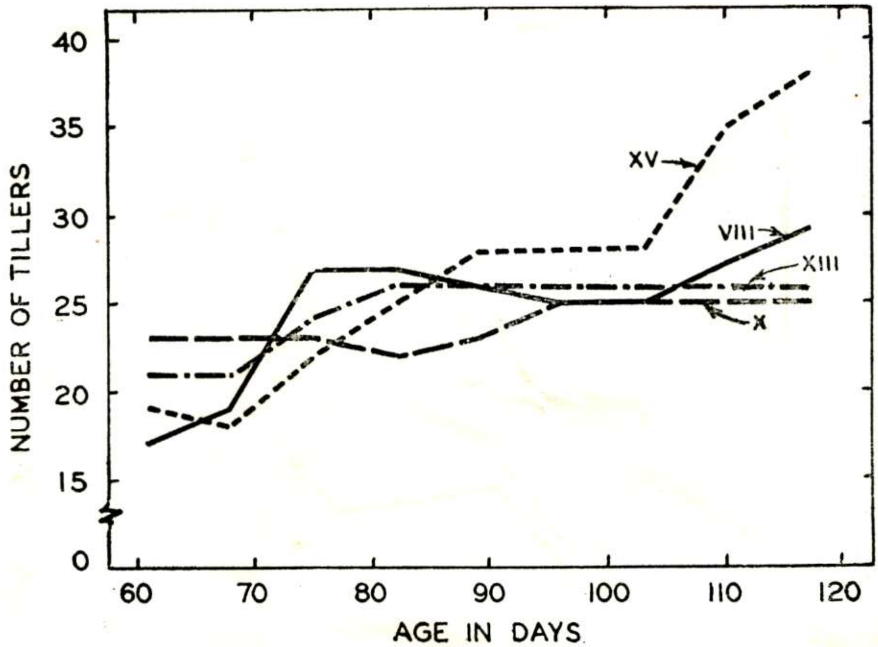

Fig. 10.—Number of tillers.

A fairly uniform flowering is desirable because of convenience in harvesting operations. Culture XV was unusual in that it conti-

TABLE 3.—*Relations between absorption of solution and dry matter produced*

CULTURE NO.	ML. OF SOLUTION ABSORBED	FRESH WT. GM.	DRY WT. GM.	ML. OF SOLUTION PER G. DRY WT.
VIII	71,530	424.08	149.20	479.42
IX	68,454	372.00	144.13	473.94
X	67,332	362.95	142.38	472.90
XI	71,694	378.40	145.63	492.30
XII	66,832	348.62	138.93	481.04
XIII	67,402	417.88	145.53	463.15
XIV	69,314	361.78	150.91	459.31
XV	65,811	388.73	145.58	452.06

nued producing new tillers and the panicles kept on emerging even when those which were formed first were already ripe. The equally high levels of phosphate and potassium in this culture may be a cause of this unusual behavior.

The average data at harvest are presented in table 4. Cultures VIII and XIII had the highest yield of grains. In the former, the ratio of phosphate to potassium was 1.5:1, in the latter, 1:2.5. This may indicate that the relationship between the two ions is rather flexible, or that they affect the plant quite independently of each other. It would seem that 1.5 meq/l is about the upper limit for phosphate. At 2 and 2.5 meq/l of phosphate, the yield of grain tends to decrease. The tendency becomes more pronounced with the concomittant increase in potassium.

High concentrations of potassium (2 and 2.5 meq/l) brought about production of more panicles. This was probably effected through the promotion of more tillers to head (96.05 and 97.28 per cent heading) rather than the formation of more tillers.

Culture X produced the best filled grains (919.5 grains per 20 grams). Apparently the higher the phosphate concentration, the better filled were the grains.

Cultures XII and XV which received 2.0 meq/l of potassium had the least-filled grains. If these observations about potassium are a general phenomenon, then potassium is a very delicate fertilizer element to manage. One has to continuously balance between the advantage of getting more tillers to head, and the disadvantage of producing unfilled or half-filled grains.

The grain-to-straw ratio was highest in culture XIII, followed by cultures XII, VIII, and IX (table 4). Culture XV had the lowest ratio. The higher the amount of grain produced in relation to the straw, the more desirable is the plant.

Cultures XIII and VIII had the highest moisture content at harvest.

DISCUSSION

From these studies, it is apparent that the needs of rice plants vary appreciably at the different stages of growth. This may be understandable considering that the principal functions of the plant during the earlier stages are the production of a maximum leaf area at the shortest possible time; during the later stages, the creation of favorable conditions for the production of maximum grain yield. In the latter phase, production of more tillers is tantamount to dissipation of material and energy which should otherwise go to the grain.

TABLE 4.—*Average data at harvest* [a]

	TREATMENT							
	VIII	IX	X	XI	XII	XIII	XIV	XV
Fresh weight of grains (gm.)	81.48	75.10	71.95	73.60	74.22	80.48	74.28	70.63
Dry weight of grains (gm.)	63.05	59.80	57.58	59.70	58.93	63.13	58.13	55.25
Number of panicles	25.2	26.5	27.75	23.8	28.0	28.2	24.5	25.8
Number of tillers	27.75	28.50	29.50	26.50	30.50	29.50	28.25	34.50
Percentage heading	90.38	92.00	94.28	89.53	96.05	97.28	96.43	82.30
Number of grains per 20 gm.	951.0	970.3	919.5	932.3	1010.3	970.5	986.5	1035.0
Percentage unfilled grains	13.95	16.10	9.62	14.07	17.17	13.27	15.47	18.75
Number of grains per panicle	120.8	103.5	96.25	119.3	101.3	106.8	107.3	102.3
Fresh weight of straw	342.6	296.9	291.0	304.8	274.4	337.4	287.5	318.1
Dry weight of straw	86.15	84.33	84.80	85.93	80.00	82.40	92.18	90.33
Ratio of fresh-to-dry weight	3.98:1	3.52:1	3.43:1	3.54:1	3.43:1	4.10:1	3.12:1	3.53:1
Grain-to-straw ratio	0.73:1	0.70:1	0.68:1	0.69:1	0.74:1	0.77:1	0.64:1	0.61:1

[a] Average of four replications, each replication representing two plants.

Since nitrogen is one major factor in vegetative growth, it should be supplied to the plant at fairly high levels in the early stages. Potassium, being involved in carbohydrate metabolism, should be in higher quantity during the later stages when starch is synthesized in great quantities in the leaves and mobilized to the grains.

In the light of these relationships, it may be worthwhile to re-examine our practice in rice fertilization. The usual recommendation is to apply at planting one-half of the needed amount of nitrogen and the full amounts of phosphate and potassium. The other half of nitrogen is applied at boot stage. The split application of nitrogen is recommended on the theory that the early application promotes leaf and tiller production. The late application promotes the production of dark-green leaves which is believed to be more efficient in photosynthesis. The beneficial effect of the second dose of nitrogen on grain yield has been demonstrated in several experiments. In fact, some agriculturists would advise foregoing the first dose but never the second. This is on the claim that the nitrogen level in most lowland rice fields is quite high early in the season. But because of the predominant anaerobic conditions, dinitrification proceeds very rapidly; hence, the need for the late dose of nitrogen. This claim has some basis in fact, but it is important that a method be devised by which a farmer can decide intelligently when to add and when not to add the second dose of nitrogen. The indications in these experiments show that as long as there is a little nitrogen in the medium to maintain the green color of the leaves, there may be no need for the second dose.

Because potassium is easily fixed by the soil, most of the potassium applied at planting cannot be expected to be available in the later stages of the plant when it would be most useful. This could be one explanation for the generally observed lack of response to potassium fertilizers. It would seem advisable therefore to explore the possibilities of late application of this fertilizer element.

The relatively low level of phosphate needed for normal growth and the sufficient amounts present in most Philippine soils are points against too serious emphasis on phosphate fertilizers. However, on account of its capacity to promote the development of a healthy root system, phosphate fertilizers may be beneficial in areas where plants have a strong tendency to root-lodge.

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